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**APPLICATION FOR LETTERS PATENT**

**Methods And Apparatuses For  
Bi-directional Signaling**

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## **TECHNICAL FIELD**

This invention relates to bi-directional signaling, and more particularly to improved methods and apparatuses for conducting and testing bi-directional signaling over a single transmission line.

## **BACKGROUND**

In a typical integrated circuit testing configuration, test signals only travel in one direction at a given time between the tester and the integrated circuit. Such uni-directional signaling works well for integrated circuits with dedicated input or output pads/pins. However, many integrated circuits are configured with input/output (I/O) circuits that support bi-directional signaling through the same pad/pin. For example, certain memory integrated circuits include I/O circuits through which access is provided to the memory. As such, data can be written to the memory by providing (inputting) applicable signals to a pad/pin of an I/O circuit. The same pad/pin of the I/O circuit can be used to read data from the memory when the I/O circuit provides (outputs) a representative signal to the pad/pin. In certain implementations, the inputting and outputting of signals associated with the memory occur simultaneously.

Fully testing the operation of such integrated circuits can be difficult if not impossible, as the uni-directional tester will need to operatively switch the signaling direction back and forth between sending test signals to the integrated circuit and receiving test signals from the integrated circuit.

By way of example, Fig. 1 depicts a conventional uni-directional signaling testing arrangement 100 configured to support limited bi-directional signaling. Arrangement 100, in this example, includes a tester device 102 operatively

coupled through a single transmission line 104 to a device under test (DUT) 106 (e.g., an integrated circuit). Here, to conduct limited bi-directional signaling over transmission line 104, tester device 102 and DUT 106 need to take turns in sending/receiving signals. Hence, this is essentially a time-multiplexed solution for conducting and testing bi-directional signaling.

As mentioned above, one of the drawbacks to testing arrangement 100 is that it is unable to conduct simultaneous bi-directional signaling. As such, DUT 106 may not be fully tested since only a portion of the operational I/O bandwidth can be tested. More specifically, the average bandwidth of transmission line 104 will be lower, because there is usually a need to pause between switching the direction of the signaling to allow the voltage in transmission line 104 to dissipate.

Hence, there is a need for arrangements that allow the full operational bandwidth to be tested.

As a basic reference, Fig. 2 depicts an exemplary receiver portion 120 of tester device 102. Here, receiver portion 120 includes a high gain comparator 122 that is configured to measure if the received signal from DUT 106 is above or below a threshold voltage level ( $V_{CMP}$ ). Comparator 122 outputs the measured voltage level ( $V_{RCV}$ ). Receiving circuits such as this and associated signal driving circuits are well known.

With this in mind, Figs 3a-b depict two common time-multiplexed testing arrangements and techniques. As shown in the example of Fig. 3a, tester device 102 includes a receiver portion represented by comparator 122, and a driver portion represented by operational amplifier 124. These portions are operatively configured to time-share transmission line 104. Here, since both the receiver and

driver portions utilize the same transmission line 104, there is a need to pause transmissions when switching to allow earlier signals to propagate.

Fig. 3b depicts a slightly improved testing arrangement, wherein dual transmission lines are provided. Here, transmission line 104a is configured to carry signals from operational amplifier 124 to DUT 106; transmission line 104b is configured to carry signals from DUT 106 to comparator 122. Because of the separate transmission lines, there is no need to wait as long for propagation delays when switching between receiver and driver portions. While this reduces the turn around time delays, the performance of the DUT cannot be fully tested, because the transmission sequence still needs to be reversed (i.e. simultaneous bi-directional signaling is not supported).

There are some test circuits that allow for simultaneous bi-directional signaling. However, such circuits are configured for use with specific devices, such as telephone devices. By way of example, Fig. 4 depicts an exemplary arrangement for providing bi-directional signaling over two transmission lines 126. As shown, this arrangement includes similarly configured transceivers (identified as Transceiver A and Transceiver B) coupled together through transmission lines 126. Since this arrangement is common to telephony, the transmission lines are usually implemented using twisted pair wires. Although detailed analysis of this well known arrangement is beyond the scope of this document, a brief conceptual description is provided below. Readers seeking additional information are directed, for example, to a text by William J. Dally and John W. Poulton, *Digital Systems Engineering*, Section 8.3, published by Cambridge University Press, March 1998.

Conceptually, the arrangement in Fig. 4 is fairly simple in operation in that each transceiver is configured to subtract its outgoing signal from the incoming signal before sampling the data. Here, for example, in Transceiver A forward voltage  $V_{\Pi}$  (which includes transmitted data  $D_{TA}$ ) is subtracted from received voltage  $V_{LA}$  using a comparator to produce received data  $D_{RA}$ . Note, that both transceivers require  $V_{L(A,B)}$  and  $V_T$  (a threshold voltage) as carried through transmission lines 126.

Ensuring that a DUT having only has a single I/O pad/pin works correctly is less straightforward. The pin electronics in most conventional semiconductor testing equipment (e.g., automated testing equipment (ATE)) can only be configured to receive or transmit data at a given time, because the test equipment receiver lacks the second externally accessible port used to cancel any outgoing signal that is applied to the DUT (i.e., as in the exemplary arrangement in Fig. 4). As such, the standard configurations for testing I/O connections are unable to test simultaneous I/O because the tester driver will interfere with data seen at the tester receiver. One possible solution to this problem would be to redesign the tester. This would likely be a very expensive engineering endeavor, since testers tend to be very precise and carefully engineered devices; for example, an average semiconductor ATE device can cost in excess of one million dollars.

Consequently, there is a need for improved methods and apparatuses for conducting bi-directional signaling and testing devices that support such bi-directional signaling.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

A more complete understanding of the various methods and apparatuses of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

Fig. 1 is a block diagram depicting an exemplary conventional signal testing arrangement having a tester device coupled through a transmission line to a device under test (DUT).

Fig. 2 is a schematic diagram depicting a portion of an exemplary prior art receiver circuit with a testing device as in Fig. 1.

Figs. 3a-b are partial schematic diagrams depicting two different prior art circuits and techniques for testing non-simultaneous bi-directional signaling using time-multiplexed test signals.

Fig. 4 is a partial schematic diagram depicting a prior art circuit and technique for simultaneously sending bi-directional signals using two transmission lines.

Fig. 5 is a schematic diagram depicting a novel circuit and technique for simultaneously sending and receiving bi-directional signals over a single transmission line to an I/O circuit in a DUT, in accordance with certain exemplary implementations of the present invention.

Fig. 6 is a time-line graph associated with the exemplary circuit of Fig. 5, which depicts selected voltages resulting from a signal output from the device under test (DUT).

Fig. 7 is a time-line graph associated with the exemplary circuit of Fig. 5, which depicts selected voltages resulting from signals output from the tester device's test driver circuits.

## **DETAILED DESCRIPTION**

Tester devices, such as ATEs, tend to come with a plurality of drivers and receivers. Referring back to Fig. 1, the end user of a general-purpose tester device 102 typically couples the DUT 106 to the tester device 102 through an intervening load board (not shown) that provides the necessary circuitry to complete the transmission line 104. It is here, for example, in the load board, or other configured interconnecting circuitry, that the methods and apparatuses, in accordance with the present invention, are implementable. One possible arrangement is depicted in the exemplary implementation of Fig. 5. Those skilled in the art will further recognize that this and similar circuitry may also be incorporated into the tester device 102 itself. Moreover, the techniques taught herein may be applied to other non-test related bi-directional communicating circuits/devices. For example, the techniques may be used whenever it is necessary to interface non-simultaneous I/O circuits (e.g., dedicated drivers and receivers) with simultaneous bi-directional circuits (e.g., I/O circuits of an integrated circuits).

With reference to Fig. 5, an arrangement 300 is depicted for conducting and testing bi-directional signaling with a targeted device, in this example, DUT 106. In addition to DUT 106, arrangement 300 includes a tester receiver 302, two tester drivers 304 and 306, and an interconnecting arrangement of transmission lines and a matching resistor network consisting of resistors  $R_1$ ,  $R_2$  and  $R_3$  (308, 310 and 312, respectively). Given this configuration, any signal that tester driver 304 outputs will be received at identified nodes C and D, but will be attenuated at node C due to resistor  $R_1$  308. Similarly, any signal that is output by tester driver 306

will also be received at nodes C and D, but will be attenuated more at node D due to resistor  $R_1$  308.

By varying the output level and subsequent attenuation of the opposing or differential signals from tester drivers 304 and 306, as received at DUT 106 (node D) and tester receiver 302 (node C), it is possible to send a non-zero signal to DUT 106 and at the same time send a substantially negligible signal to tester receiver 302 (node C).

Preferably, the signal output by tester driver 306 reduces the opposing signal output by tester driver 304 at tester receiver 302 (node C) to the point where the signal from tester driver 306 is effectively cancelled or rendered negligible. This allows signals output by DUT 106 to be received by tester receiver 302 without interference from the drivers 304 and 306. The signal ( $V_A$ ) output by tester driver 304 will be strong enough to be received by DUT 106 (node D) despite being reduced slightly by the opposing signal ( $V_B$ ) output by tester driver 306.

In other words, the combination of the signals from tester drivers 304 and 306 resulting from the resistor network, at the DUT 106 (node D), is going to be a signal of appropriate magnitude and other characteristics such that it mimics or otherwise matches what would be seen from a dedicated driver circuit normally used to test an input pin of DUT 106. With respect to tester receiver 302 (node C), the resistor network combines the signals from tester drivers 304 and 306 in a manner such that the resultant signal at node C is at a magnitude that is essentially negligible (e.g., within a noise level) to tester receiver 302 and does not, therefore, interfere with other signals received at node C, for example, as output by DUT 106. Note also that the signal from DUT 106 is presented with matched



impedance by the resistor network such that reflections are not sent back along the transmission line.

In a particular example, tester driver 304 provides the test drive signal that is represented in the resultant signal as applied to DUT 106 (node D); conversely, tester driver 306 provides a cancel signal that, when combined through the resistor network, causes most if not all of the drive signal from tester driver 304 to be attenuated at node C.

In accordance with certain exemplary implementations, the resistive network (or another like combining circuit) is included in a load board 313 as represented by the dashed line box. Load board 313 may also include one or more transmission lines and related connectors including one or more connectors or sockets for receiving the DUT.

As illustratively depicted in exemplary arrangement 300, the transmission lines between tester receiver 302, tester drivers 304 and 306, and DUT 106 have the same impedance ( $Z_0$ ). Consequently, to eliminate reflections tester receiver 302, tester drivers 304 and 306, and DUT 106 include impedance matching resistors ( $R_0$ ), which match impedance ( $Z_0$ ). Similarly, matching resistor  $R_1$  (308) is configured to match impedance ( $Z_0$ ). There are a plurality of values that can be applied to resistors  $R_2$  and  $R_3$  (310 and 312, respectively), based on the driver signal voltages  $V_A$  and  $V_B$ . By way of example, in certain implementations, the following values were used:

$$R_1 = Z_0, R_2 = R_3 = 1.4142 * Z_0, V_A = 5.83 \text{ V}, \text{ and } V_B = -0.4142 * V_A.$$

Here, for example, the resistive values of  $R_2$  and  $R_3$  can be selected based on two criteria. First, the values are selected such that a selected driver signal voltage  $V_B$  will substantially cancel out driver signal voltage  $V_A$  at node C.

Secondly, the values are selected such that at least an appropriate amount of driver signal voltage  $V_A$  is present at node D.

Fig. 6 is a time-line graph associated with a SPICE simulation of exemplary arrangement 300, which depicts selected voltage levels resulting from a signal output from DUT 106. Here, the data transmission represented by line 400, begins in DUT 106 at about 1 nS with a voltage of about 1 V. This voltage is reduced by about 50% at node D, as depicted by line 402. In this example, this initial attenuation is due to source termination within the output driver of the DUT 106. After a slight propagation delay, the signal, attenuated by another 50% (resulting in about 0.25 V as represented by line 404) is received at node C in the tester receiver. As illustrated, essentially none of the signal energy is reflected back to DUT 106 from the matching network because the resistive network is configured to impedance match the transmission line between DUT 106 and the resistive network.

Fig. 7 is also time-line graph associated with a SPICE simulation of exemplary arrangement 300, which depicts selected voltage levels resulting from signals output from tester driver 304 and tester driver 306. Here, tester driver 304 and tester driver 306 are configured to begin outputting their respective opposing signals at about 1 nS. Line 408 represents the voltage at node A, as output by tester driver 304. Line 410 represents the voltage at node B, as output by tester driver 306. Line 412 represents the voltage received at DUT 106 (node D). Here, the resulting received voltage at DUT 106 (at about 3 nS) is approximately 1.0 V as a result of the combined driver voltages (represented by lines 408 and 410) wherein the drive signal (408) is attenuated in the resistive network by the opposing cancel signal (410). Furthermore, line 414, which as shown is

substantially steady at about zero volts, represents the voltage received at tester receiver 302 (node C) due to the combination of the drive and cancel signals output from tester drivers 304 and 306, respectively. Note that there may be some slight reflection back to the tester drivers.

Therefore, as shown in Fig. 7, a resultant signal derived from the signals from tester drivers 304 and 306 will be received by DUT 106 but not significantly seen at the input to comparator 122 in tester receiver 302. As shown in Fig. 6, simultaneously transmitted signals from DUT 106 will be received at comparator 122. Thus, arrangement 300 supports simultaneous bi-directional signaling and related testing.

Although some preferred implementations of the various methods and apparatuses of the present invention have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the invention is not limited to the exemplary implementations disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the spirit of the invention as set forth and defined by the following claims.